Quantification of Fugitive Methane Emissions by Inverse Dispersion Modelling in the Oil Sands and Coal Mines

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Redefining possible.

Outline

- Context

- Oil Sand Mines

  - CALPUFF-IDM since 2015

- Coal Mines:

  - CALPUFF-IDM first!

- Final Thoughts

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Methane Quantification and Mitigation Landscape

1. **GHG cause Global Warming and Climate Change**

2. **Methane's Global Warming Potential is ~28** (over 100 years)

3. **Increasing Carbon Prices** ($65 per tonne of $CO_{2\,eq}$, growing to $170 by 2030 in Canada)

4. **Net Zero Pledge**

5. **Path to NetZero requires:**
   - **a realistic GHG baseline**
   - **targeted mitigation**
   - **means to assess success and quantify reductions**

6. **Fugitive emission estimates from large area sources** (oil sand mines, coal mines, landfills, upstream plays with gas wells) **are currently not precise enough (spatially and/or temporally)** (be it Flux chambers, emission factors, remote sensing by drones, planes/satellites)

Quantifying Fugitive Methane Emissions

Ideal Method for large area sources

- Accurate
- Spatially & temporally representative
- Enables targeted mitigation
- Consistent

- Cost effective
- Safe
- Reasonable Turn-around
- Accepted by regulators

Typical Methods : *have limitations*

- Flux Chambers for Oil Sands
- Historical Emission Factors for Coal Mines

Alternative : CALPUFF-IDM

OIL SANDS MINES & TAILINGS PONDS

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Site Constraints

- Soil Heterogeneity – Cracks – Bubbling Zones

- Complex Terrain

- Inaccessible areas including

  - sandy zones in tailings ponds, and

  - toes and vertical faces in the mine

  - Active operating mining areas

Toes and Vertical Faces – Fresh ore, high emissions - unsafe

Ongoing Operations
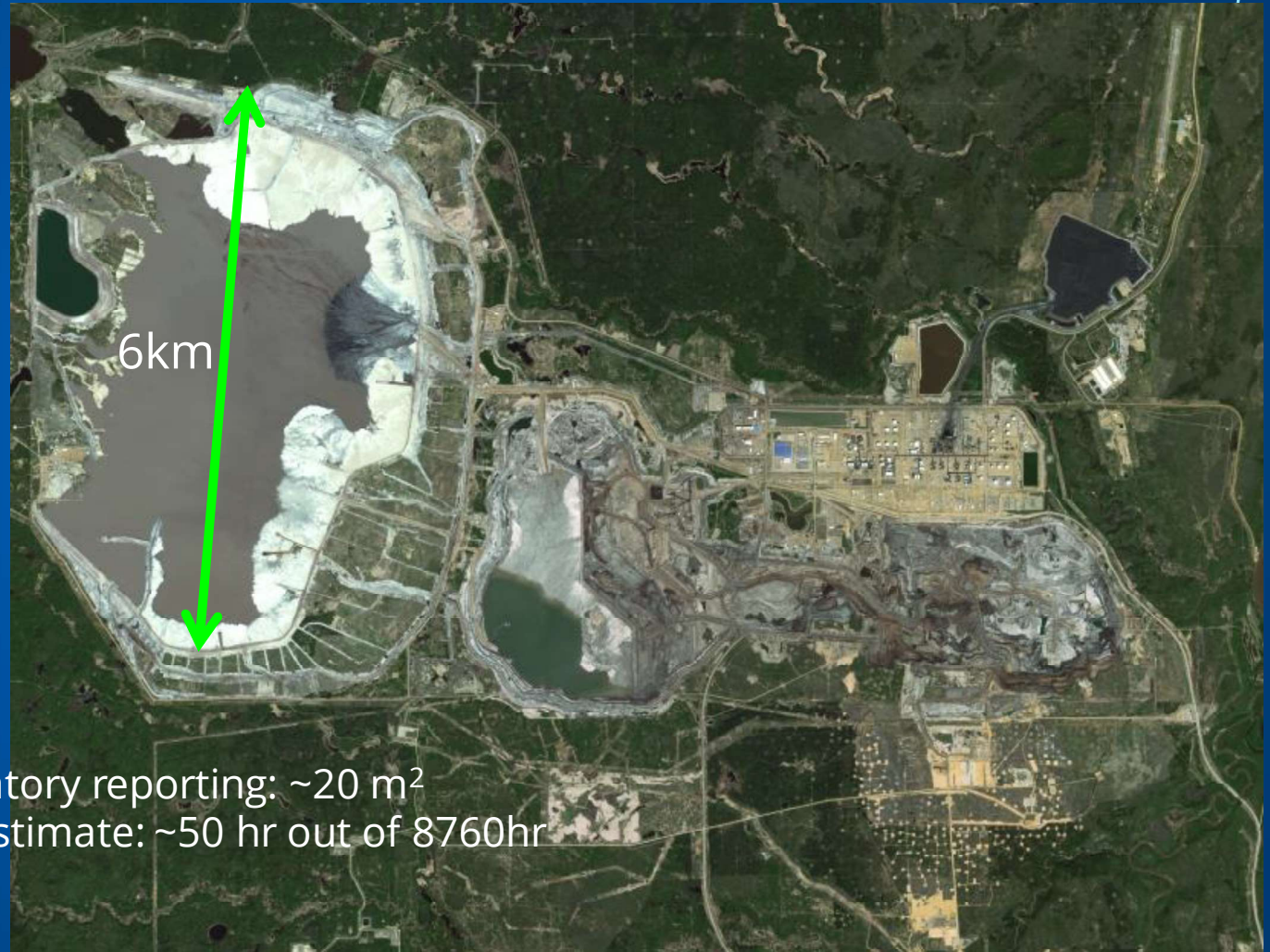(no access)

Bubbling in the mine - seepage

Tailings Pond:
- Open water
- Slick
- Sandy Areas (unsafe)

Traditional approach: flux chambers in summer

tiny footprint
brief sampling time

40cm
30 min

6km

Total Area sampled for regulatory reporting: ~20 m²
Total time spent for annual estimate: ~50 hr out of 8760hr

Alternative Method:
Ambient Monitoring + Inverse Dispersion Modelling (IDM)

- Since 2015 for regulatory reporting

- Under scrutiny of AEP (EPA)

- Validated / 3rd party assessed (ERA study)

- CALPUFF-IDM has become an official regulatory alternative to flux chambers

 (*Quantification of Area Fugitive Emissions at Oil Sands Mines, Vol 2.2, Alberta Environment and Parks, Draft*).

Several days
Several monitors
Changing winds
Whole area is sampled

Downstream
-
Upstream
=
Source
Contribution

IDM – Methane Sensors – Sonic Anemometers

Los Gatos Research (LGR) Ultraportable Greenhouse Gas Analyzer (UGGA) (CH_4/CO_2) + LICOR - Solar-Powered

Anemometers
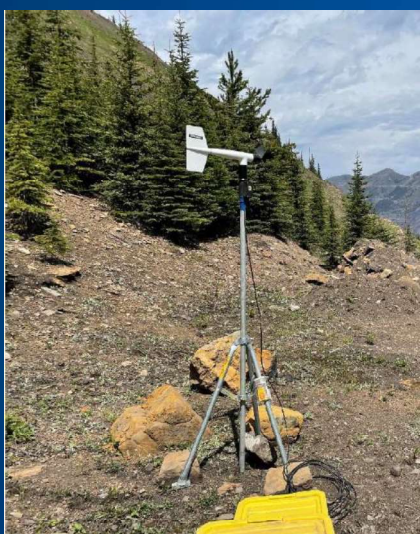
Other sensors have been used for validation/benchmarking/comparison:
-   Open Path Lasers (found to be unstable and with large uncertainties)
-   FTIR: excellent to benchmark concentrations at one location but costly and not portable (Univ. of Alberta)
-   Eddy Covariance: very good over small flat surfaces (e.g. tailings ponds)
-   Drones: hot spot match only so far (during ERA study in Oil Sands and more recently at coal mine)
-   Flux Chambers (too spotty in space and time)
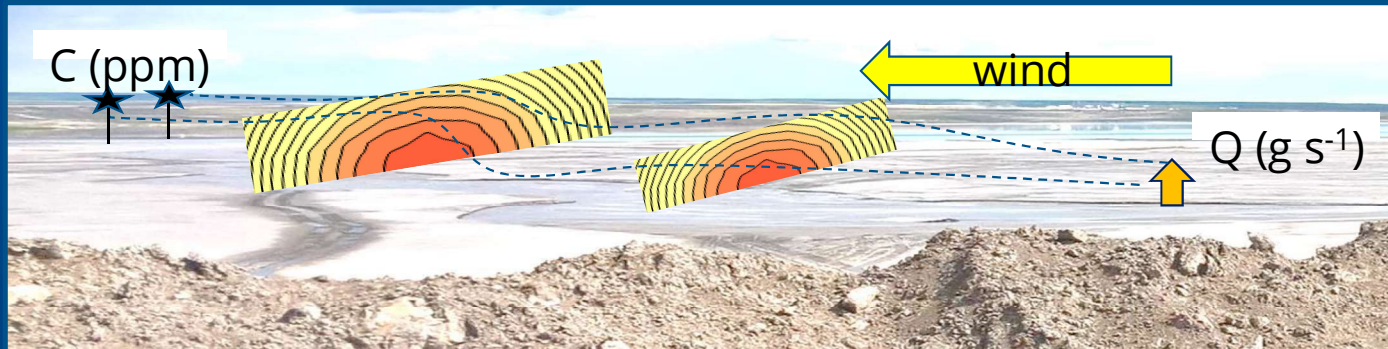
INVERSE DISPERSION MODELLING (IDM)

1. Monitor

Ambient monitoring around mine perimeter GHG concentrations + Meteorological Observations

2. Model

Meteorology: Obs./WRF/CALMET ***Dispersion:*** CALPUFF (puff lagrangian model – key)

3. Invert and Quantify

Reconcile modelling results with ***measured*** GHG concentrations (Bayesian approach) => **GHG emissions**

C (ppm)

wind

Q (g s^{-1})

IDM answers the question: What should the emission rates be to cause the observed concentrations?

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INVERSE DISPERSION MODELLING (CALPUFF-IDM)

1. Meteorological Modelling:

- **Mesoscale Modelling** (WRF) at 3km resolution (1km for the coal mine) resolution and 1hr timestep for overall mesoscale winds in the area over the campaign period

- **CALMET Modelling** down to **50m** resolution in the Oil Sands (and 10m resolution in coal mine) **and 15-minute timesteps** in the pit: requires to merge in mesoscale fields and observations, high resolution terrain elevations and land use data

2. Dispersion Modelling:

- **CALPUFF modelling** for 1000s mini area sources aggregated by operational zones

- Assign unit emission intensity to all mini area sources and model impact at monitoring locations, at all times

3. Emission Mapping and Quantification ("INVERSION")

- Bayesian Approach to match modelled and observed impacts at monitoring locations by deriving appropriate emission rates for each operational zone (this is often referred to as the "inversion" step, not to be confused with the atmospheric inversion that develops in the mine overnight).
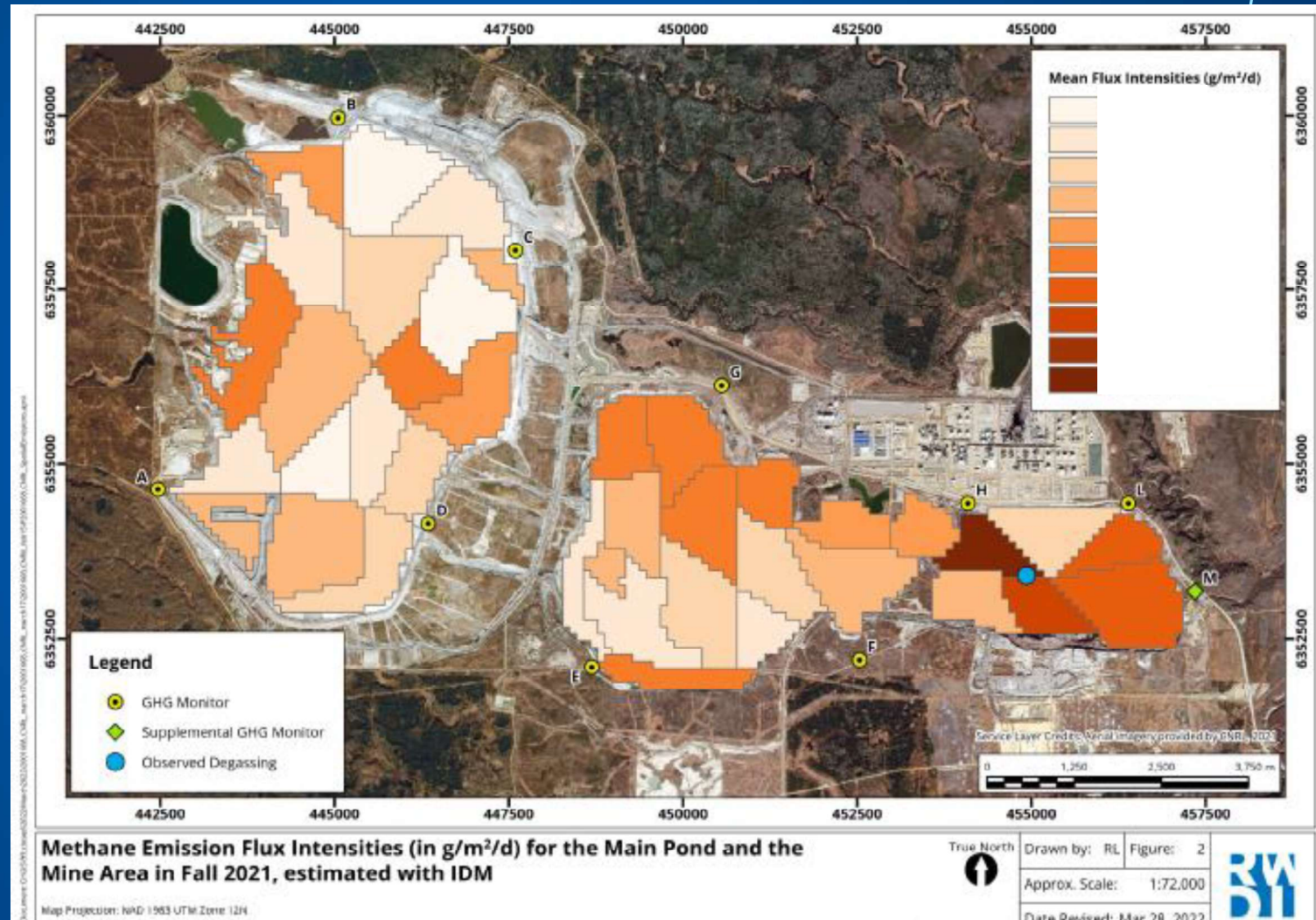
2D Mapping of Methane Emissions

Estimate Includes
- sandy areas of the tailings ponds,
- bubbling zones, cracks toes, vertical faces of the mine
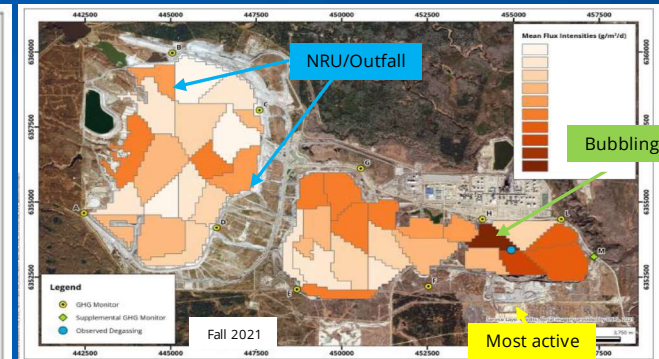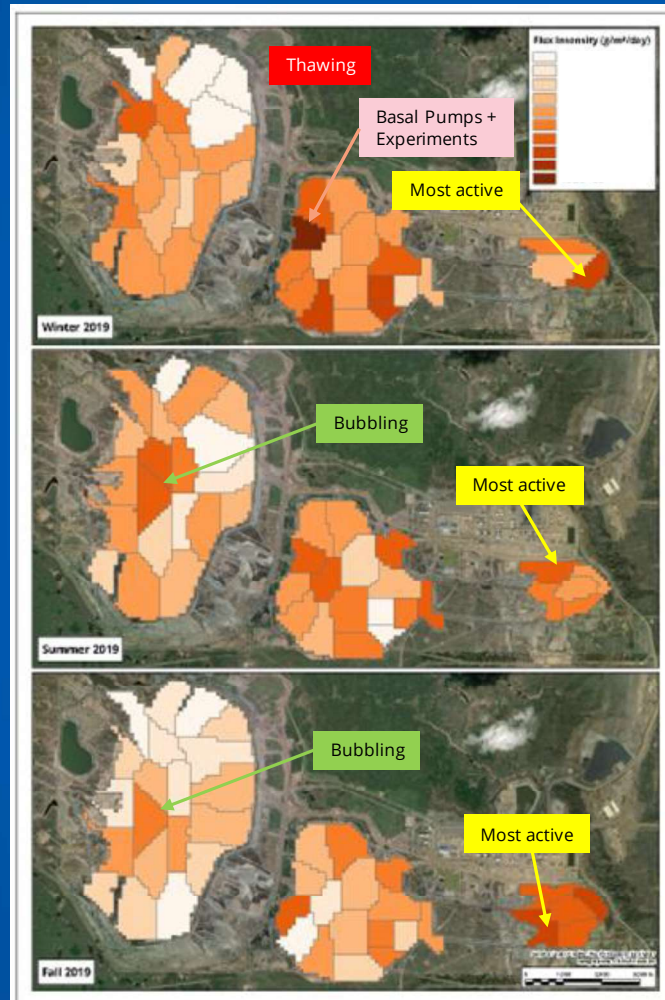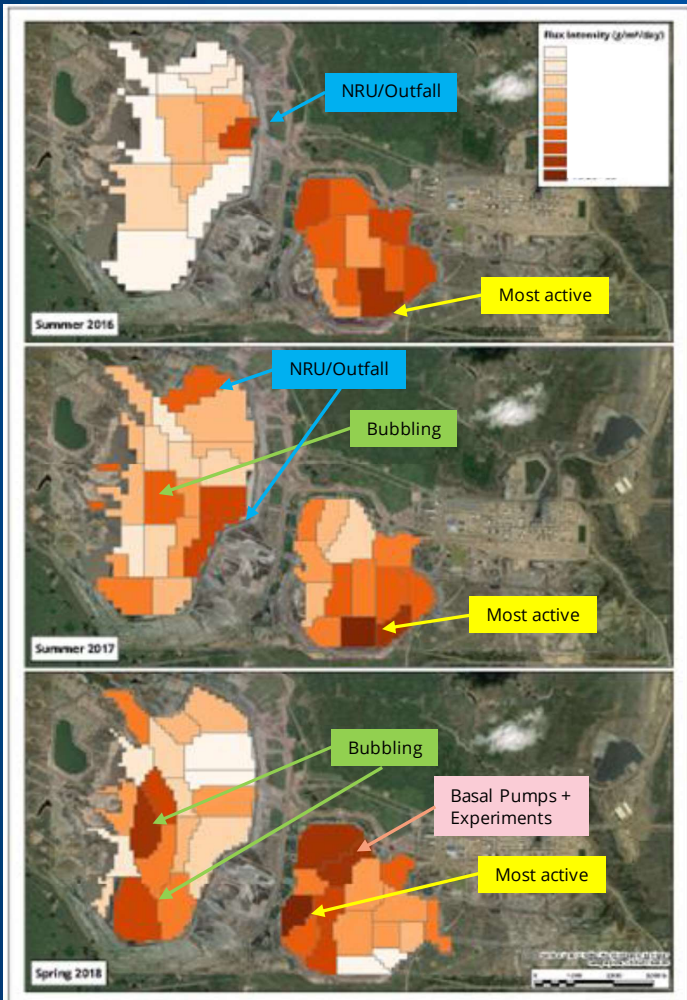
Has helped discovering unexpected hot spots

More accurate, more comprehensive

Possibly larger emissions rates identified, but supports credible path to netZero and meaningful targeted mitigation

Methane Emission Flux Intensities (in g/m²/d) for the Main Pond and the Mine Area in Fall 2021, estimated with IDM

Legend
- GHG Monitor
- Supplemental GHG Monitor
- Observed Degassing
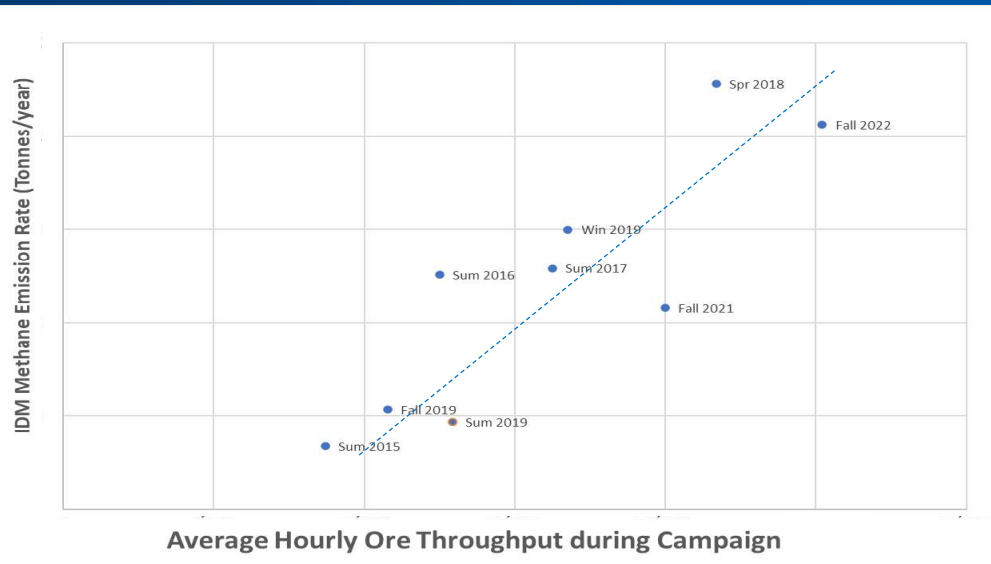
Mean Flux Intensities (g/m²/d)

Historical Methane Emission Intensities

High emission intensities consistently from:
- highly active mining areas
- NRU/Outfall/Slick
- bubbling zones (in the pond and in the mine)
- Ore processing areas

New: Annual Extrapolation – pro-rated by ore throughput

- Consistency = same overall mine emission rate every campaign
- Consistency between hot spots/mine activities
- Established correlation (0.87) between IDM-based CH_4 emission rates and ore throughput during the 9 seasonal campaigns since 2015
- Allows to extrapolate emission rate established during 5-day campaign to an annual emission rate based on hourly ore throughput during the year

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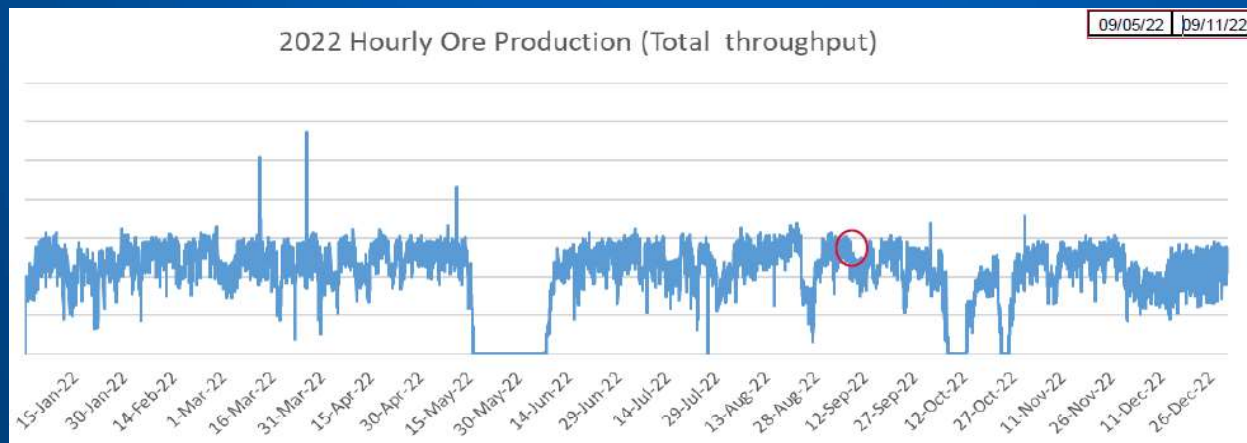
CALPUFF-IDM Oil Sands

CALPUFF-IDM is the only alternative method to obtain approval for CH_4 quantification of large fugitive area sources in the Alberta Oil Sands

Consistent estimates that can be correlated with site specific activities for more accurate emission forecasting

CALPUFF-IDM enables fine resolution identification of "hotspots" for targeted mitigation

Intrinsic safety factor for monitoring emissions.

Easily deployable year-round

Real-time & Online Display Possible

New regs give nod to Coal Mines as well

COAL MINES
Coal Bed Methane

Recent Coal Mine Methane news

After COP26, we need less talk and more action
20 November 2021

Satellite imagery suggests emissions may exceed what mining companies have been reporting *(Financial Times, Melbourne, June 21, 2022)*

CALPUFF-IDM for Coal Mines   - A first!

1. **Monitoring Campaign:**

    - 3-day meteorological and CH_4 monitoring campaign at operating open pit coal mine

    - Similar set up as for Oil Sands (monitoring in and around the much deeper pit)

2. **Met and dispersion modelling:**

    - WRF/CALMET then CALPUFF modelling for 1000s mini area sources using high-resolution winds and meteorology)

    - Mini-areas aggregated to match operational zones (blasting, new and old drill patterns, loading areas, haul roads, exposed coal seams, etc.)
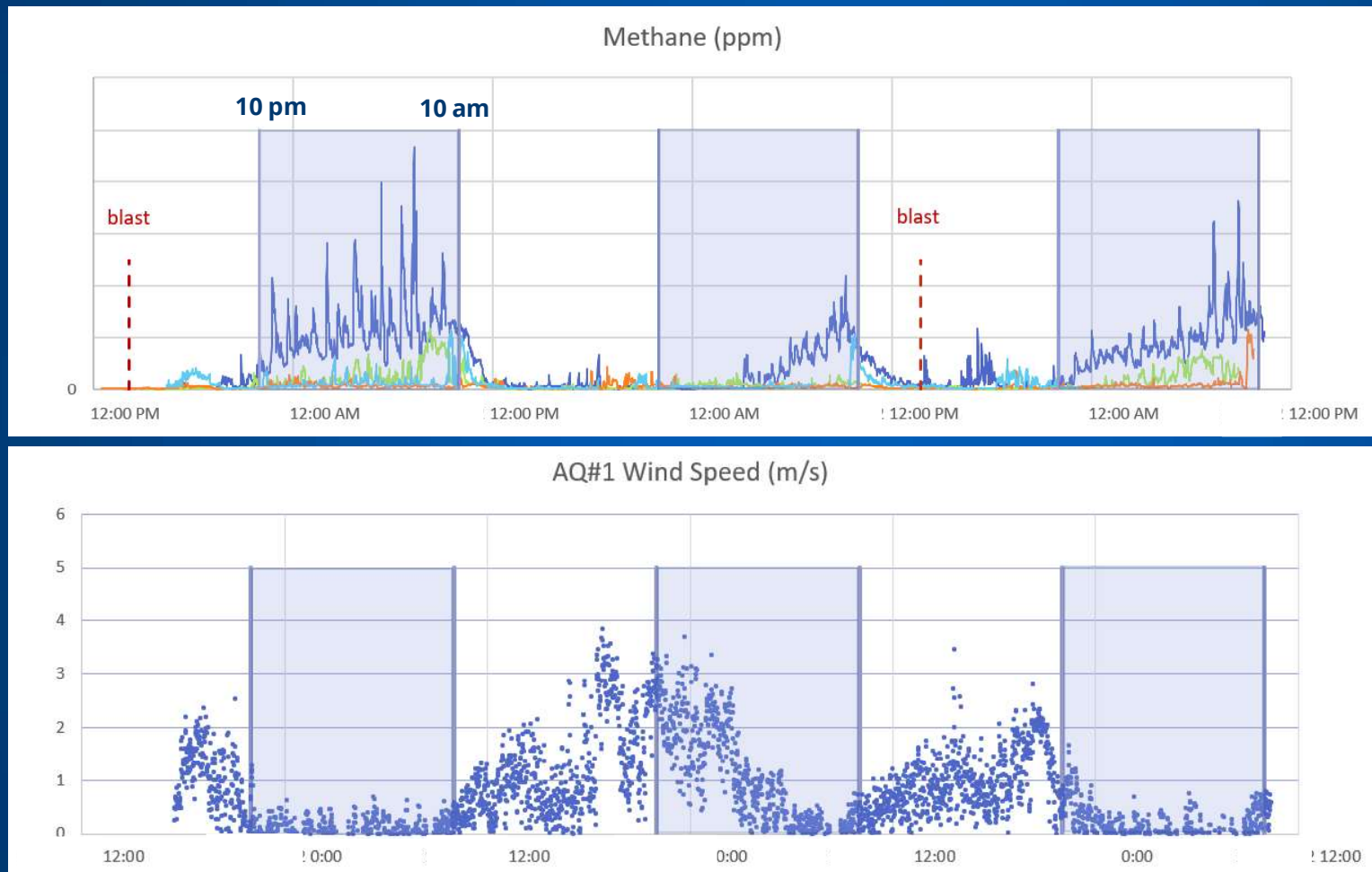
3. **Inversion**

    - Important to have identified meaningful and coherent areas for accuracy and insightful interpretation of results (operation-based emission factors, hotspots, avoid smearing, reduce uncertainties, faster algorithm convergence …)
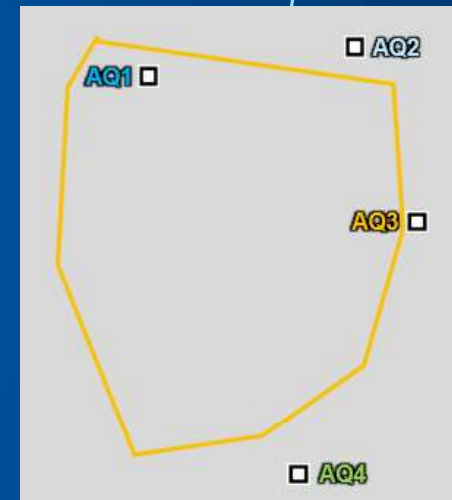
Monitoring Campaign

MET1 ▲

AQ2 ▢

AQ1 ▢

CH$_4$ / Wind /T ▢
Wind/T ▲

AQ3 ▢

MET2 ▲

AQ4 ▢

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Continuous CH$_4$ Monitoring

Methane (ppm)

10 pm   10 am

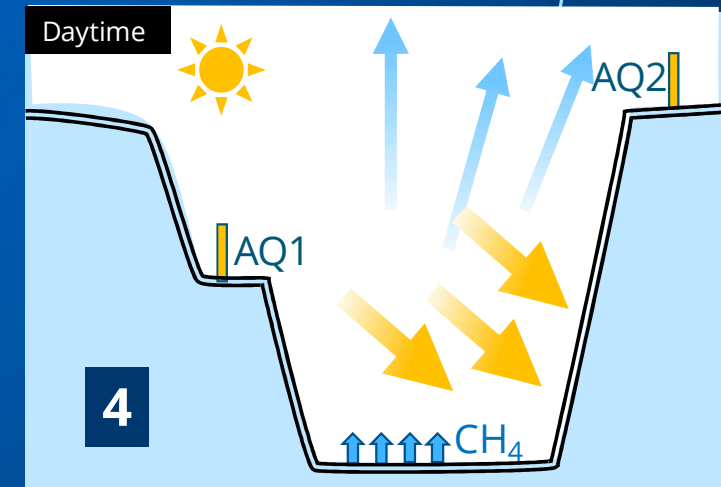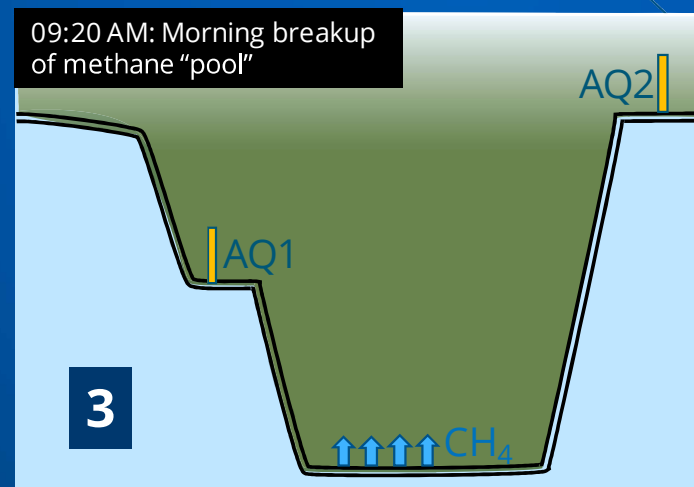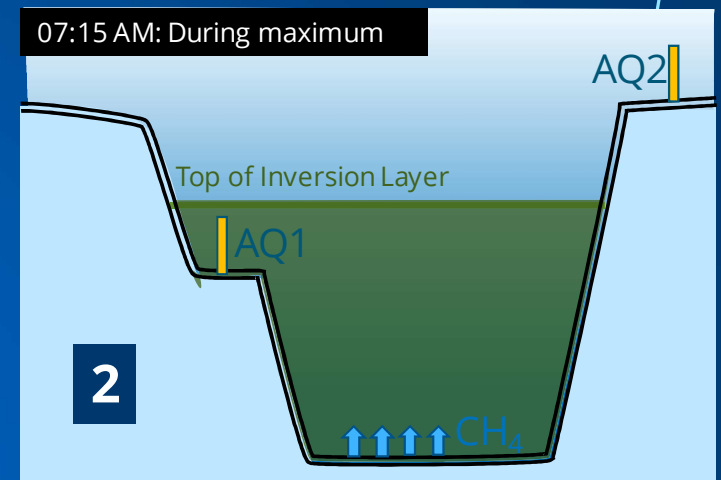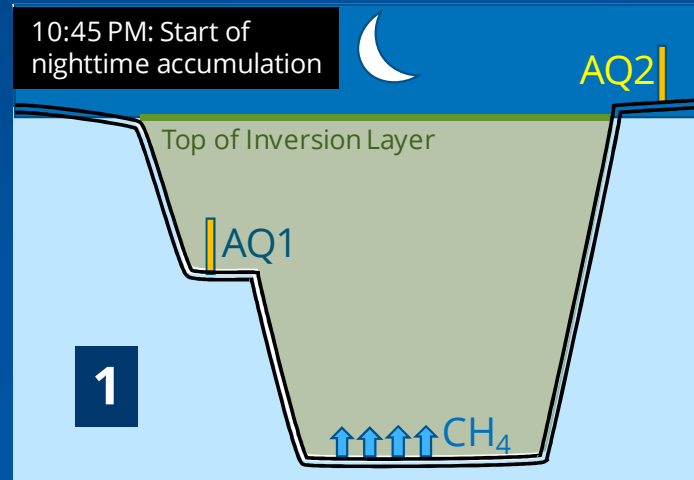blast   blast

AQ#1 Wind Speed (m/s)

AQ1: at edge of the pit but below the nighttime inversion

What's Happening?

1. Nighttime cooling forms temperature inversion, trapping CH_4 inside the pit. Cooling and accumulation continues overnight

2. Concentrations inside the pit (AQ1) reaches a maximum in early morning

3. Methane breaks out of "pool" and reaches stations on mine rim (AQ2) as sunlight begins heating up the mine floor.

4. Daytime concentrations remain low as sunlight continues to heat up the mine surfaces, allowing methane to escape through convection and advection

10:45 PM: Start of nighttime accumulation
AQ2
Top of Inversion Layer
AQ1
CH_4
1

07:15 AM: During maximum
AQ2
Top of Inversion Layer
AQ1
CH_4
2

09:20 AM: Morning breakup of methane "pool"
AQ2
AQ1
CH_4
3

Daytime
AQ2
AQ1
CH_4
4

Consequences of the Pit Dynamics

1. **IDM:**
   - Inversion height and behavior are critical: requires good met observations and met model
   - Absolutely needs a dispersion model that can handle 3D meteorology and stagnation (CALPUFF)

2. **DRONES:**
   - Best flights in early morning in stable conditions inside the pit i.e. drones sample concentrations reflective of emissions accumulated throughout the night => overestimated
   - During (late) daytime: helpful to delineate relative emission strengths/ sub-areas
   - Could be used in vertical flight pattern to determine inversion height and cross-validate met model

3. **PLANE and SATELLITE SURVEYS:**
   - Scant data collection
   - Early morning passes might pick the morning emission "burp"

Coal Mine Campaign - Outcome

1. **2D Map of emission rates and emission intensities**

2. **High Emitters:**

    - Newly drilled/blasted areas

    - Exposed coal seams

3. **Blast:**

    - Blast's unique signature could be isolated and blast emissions estimated independently of rest of the mine

4. **Challenges:**

    - daytime vs. nighttime regimes

    - High day-to-day week-to-week variability of mine activity will require continuous monitoring and/or multiple mine campaigns to identify reliable operation-based emission factors and refined production correlation

Summary

1. CALPUFF-IDM:

- Substantial advancement over current point, drones and satellite estimates.
- Improved quantification of fugitive methane emissions from large mines (Oil Sands and Coal)
- Representative 2D mapping of methane sources allowing operation-specific emission estimates and targeted mitigation
- Safe remote sampling
- Potential to apply continuously
- Scrutinized and approved by AB regulator.

2. Oil Sands mines:

- More accurate, i.e. often larger, methane emission estimates with CALPUFF-IDM than Flux Chambers as the approach takes into account emissions from otherwise unsampled zones (sandy areas at the pond, toes, vertical faces, bubbling zones and cracks at the mine)
- Newly established correlation with ore throughput, allowing annual modulation of campaign estimates and forecast

3. Coal mines:

- First Successful IDM campaign in Fall 2022
- Methane trapping at night and morning "burp" require careful timing of any measurement and quantification method.

Thank you!

Redefining possible.

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